Additives to Increase Fuel Heat Sink Capacity

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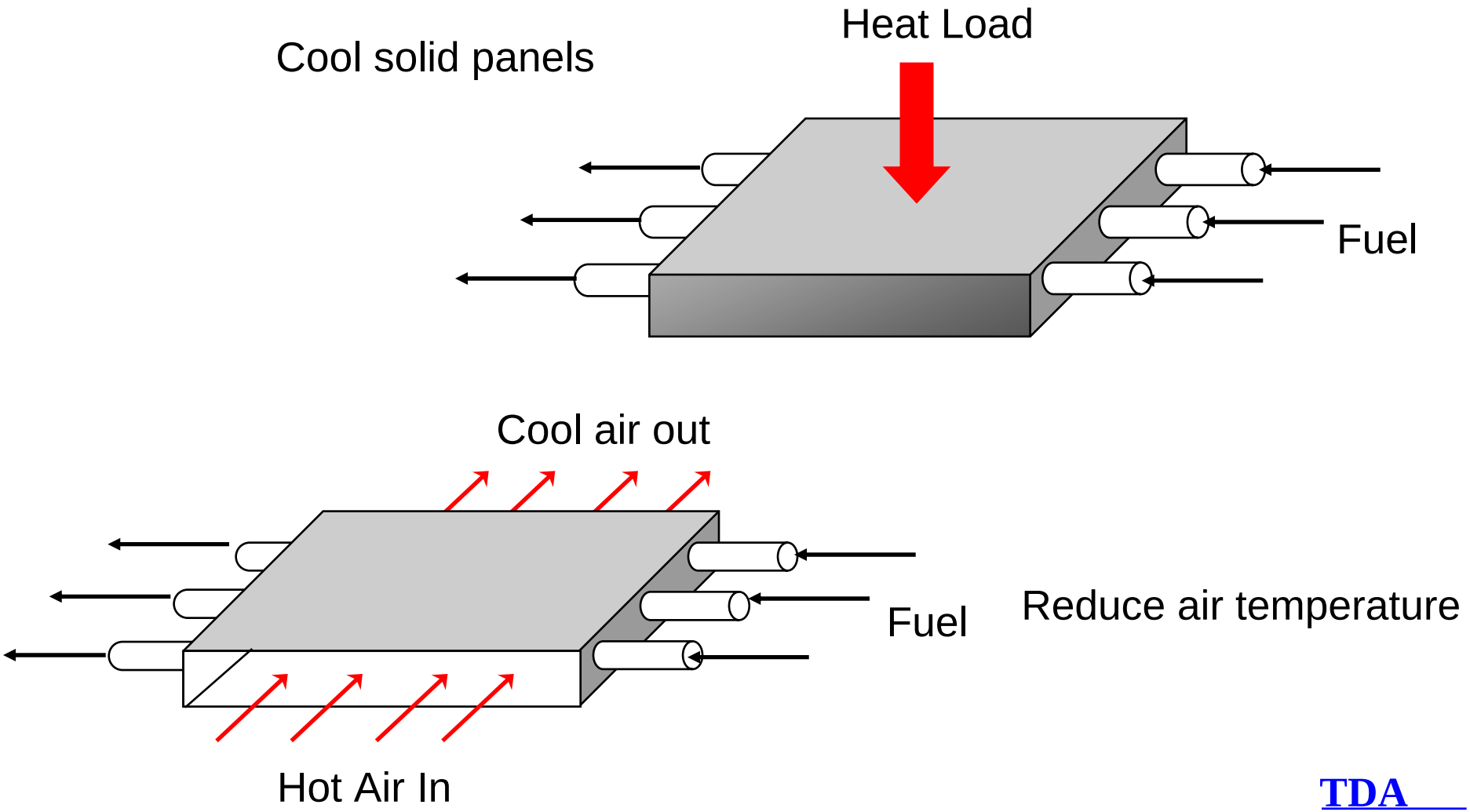
Overview

- Application of endothermic fuels.
- Initiated thermal cracking reactions.
- Results of laboratory experiments to measure initiated heat sink capacity.
- Results obtained with pilot scale fuel/air heat exchanger.

NASA Application for Endothermic Fuels

- Improve commercial access to space.
  - Current cost is about $10,000 per pound.
  - Goal is to reduce cost to $100 per pound.
- Cost reductions will require:
  - Single stage to orbit (SSTO) vehicles.
  - Rocket-based combined cycle (RBCC) engines using hydrocarbon fuel.
- At speeds between Mach 5 and 10, heat loads exceed cooling available from sensible heating of the fuel.
- Thermal cracking reactions may provide the additional heat sink capacity.

Applications of Endothermic Fuel Cooling



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Thermal Cracking Reactions

- Heptane cracking.

$$C_7H_{16} \longrightarrow CH_4 + C_2H_4 + C_2H_6 + C_3H_6 + C_3H_8 + \ldots \qquad \Delta H \approx +400 \text{ Btu/lb}$$

- Proceeds by a free radical mechanism.

Initiation - slow step

$$C_7H_{16} \rightarrow C_7H_{15}\bullet + H\bullet$$

Ethylene formation by β scission - fast

$$C_7H_{15}\bullet \rightarrow C_2H_4 + C_5H_{11}\bullet$$

Chain propagation - fast

$$C_7H_{16} + CH_3\bullet \rightarrow C_7H_{15}\bullet + CH_4$$

- The overall rate is limited by the initiation step, which is slow at working temperatures.

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Addition of Chemical Initiator

- Increases the rate of radical generation because the R-R bond is weaker than the C-H bond.

$$R\text{-}R_1 \rightarrow R\bullet + R_1\bullet$$

- R• and R_1• then react with the fuel.

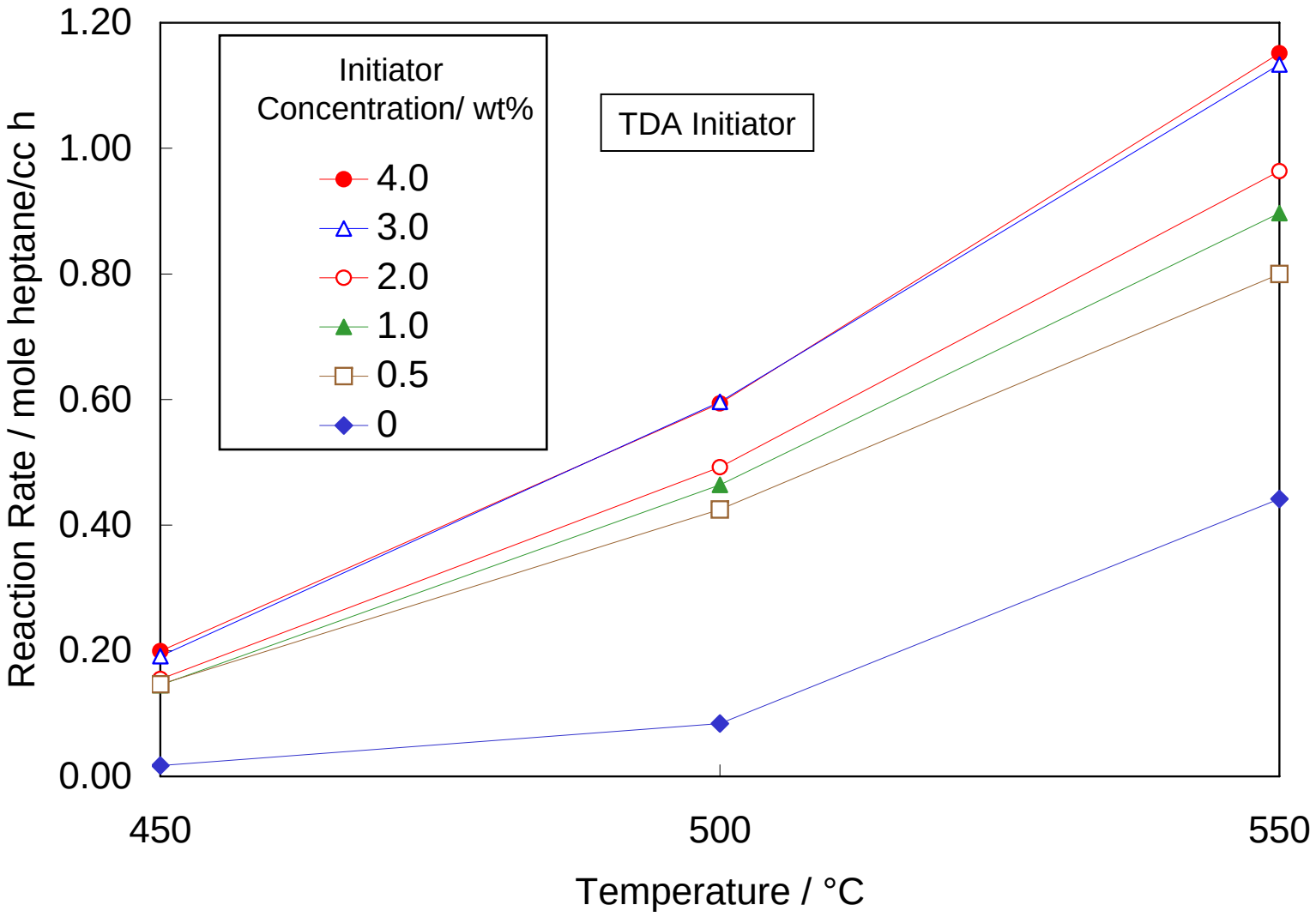
$$R\bullet + C_7H_{16} \rightarrow C_7H_{15}\bullet + R\text{-}H$$

- The rest of the process is identical to the mechanism without the initiator.
  - The chemical initiator only starts the reaction - it has no effect on reaction stoichiometry.
- Low concentrations required (less than 3 wt%).

Characteristics of the TDA Initiator

- Consists of carbon, hydrogen, and oxygen.
- Is soluble in normal paraffin fuels.
- Is stable in its concentrated form at ambient temperatures.
- It is not a highly toxic chemical.

Previous Results with n-Heptane



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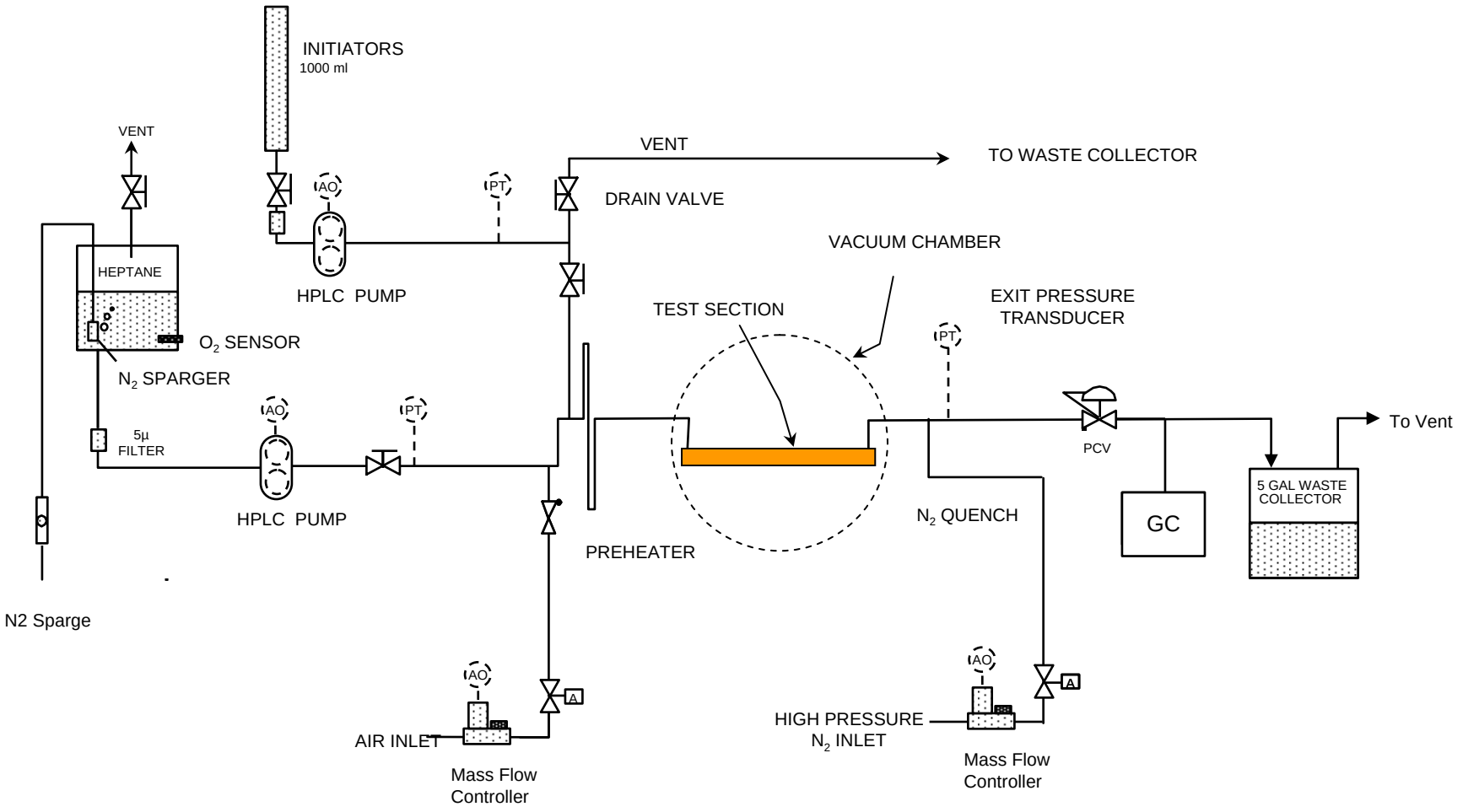
Objective of Current Project

- Measure heat sink capacity of real fuels such as JP-7 with and without initiator.
- Use kinetic data to design and construct a pilot scale heat exchanger and demonstrate initiator under realistic heat flux.

Laboratory Apparatus



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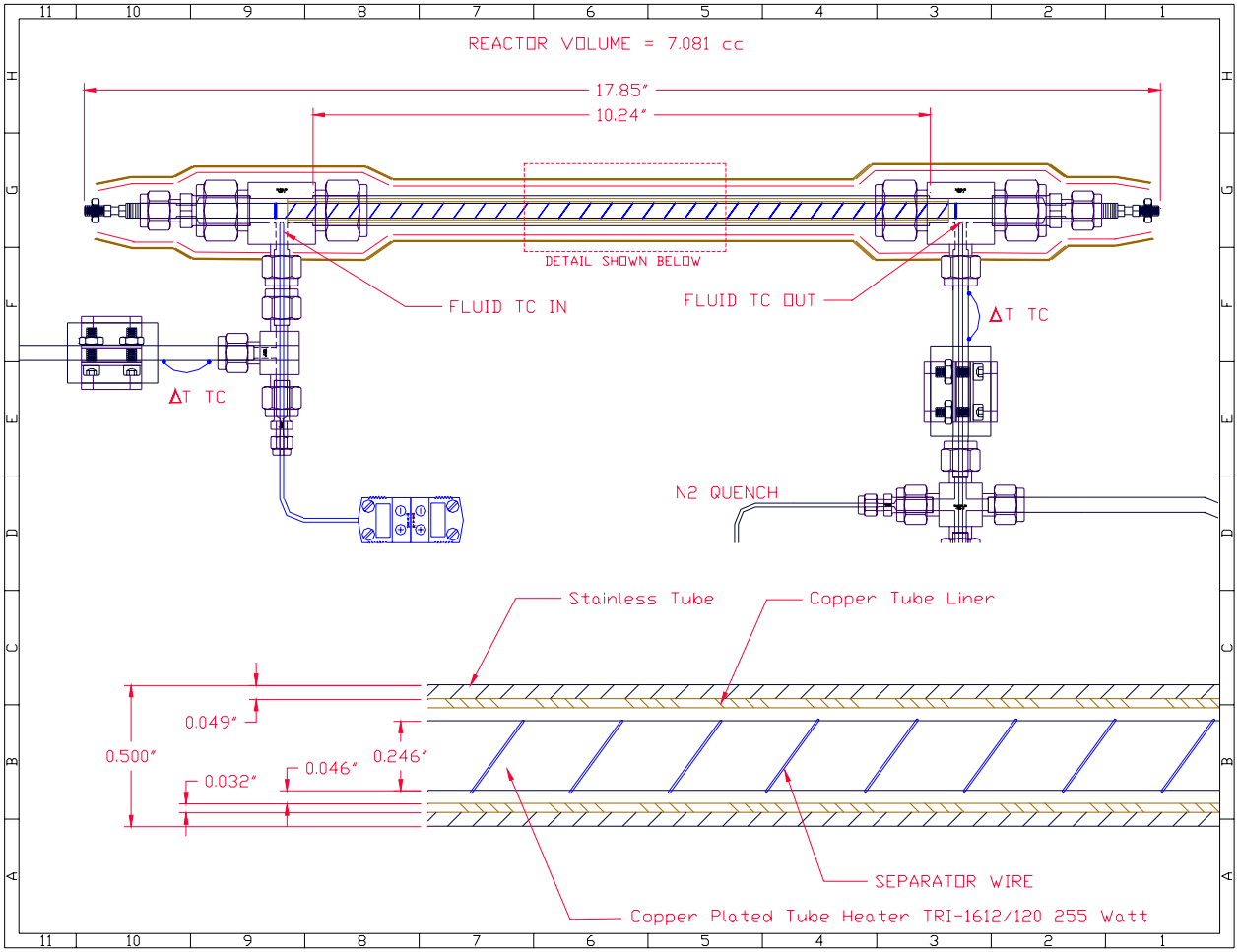
Test Section Used Annular Fuel Flow Path



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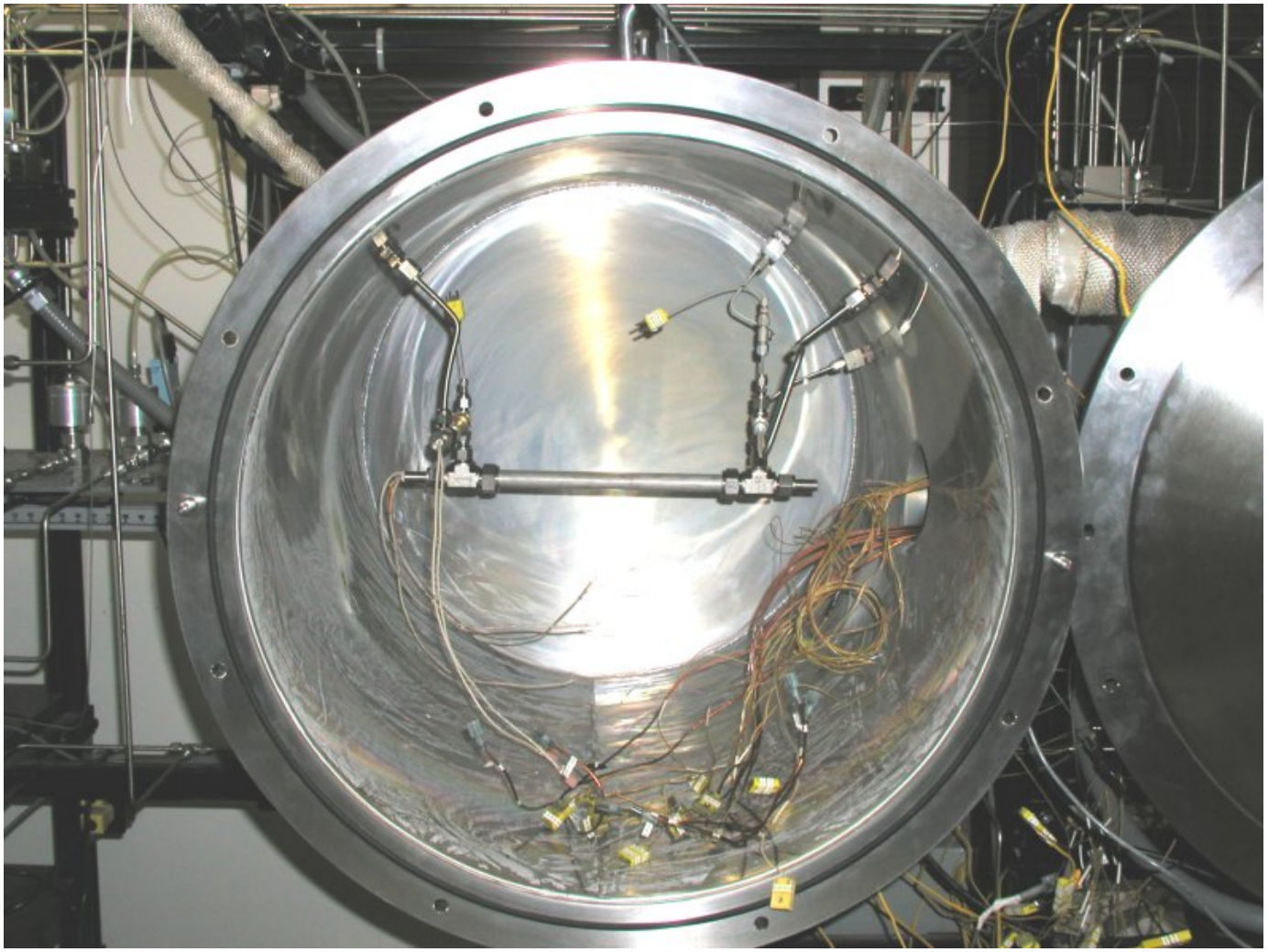
Test Section Installed in a Vacuum Chamber to Reduce Convective Losses



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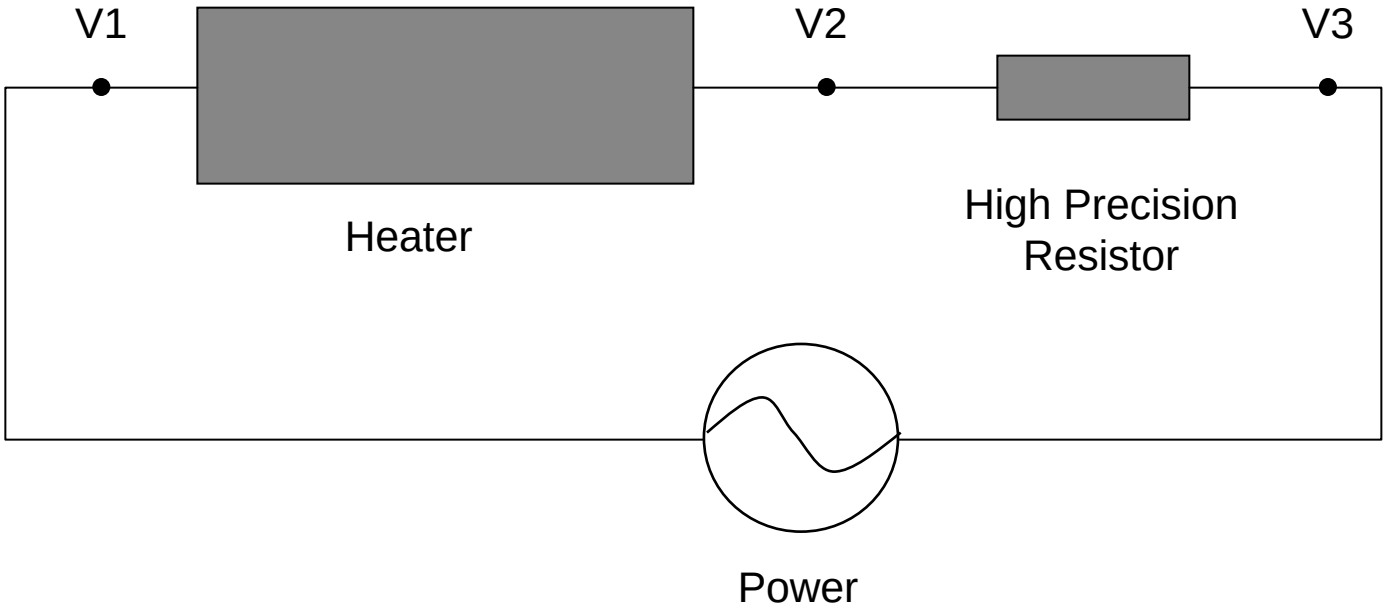
Power Measurement



Power = V * I
V = V1 - V2
I = (V2 - V3) / r

Measurements were made at 1000 Hz with a digital oscilloscope

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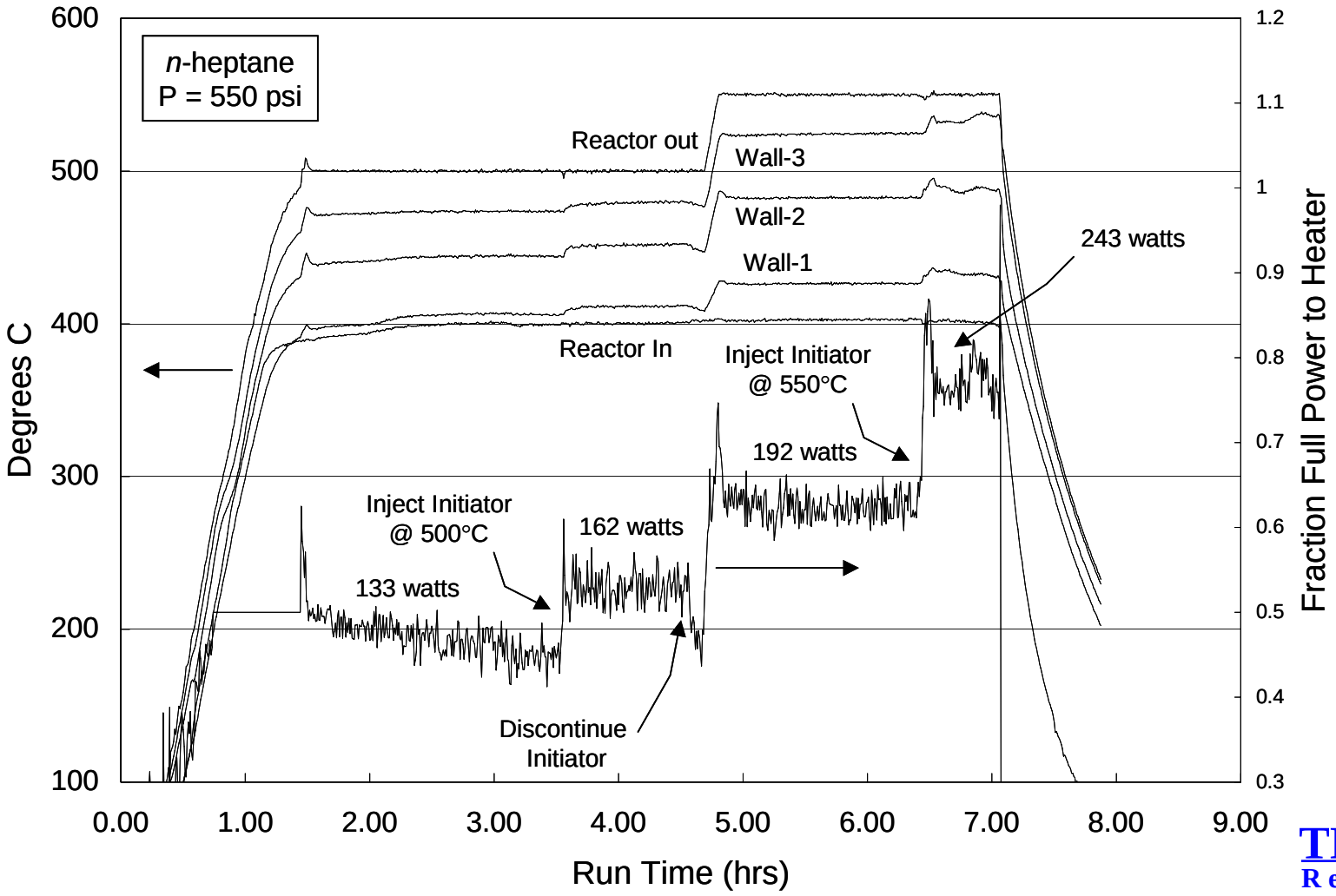
Significant Power Increase with Initiator Addition



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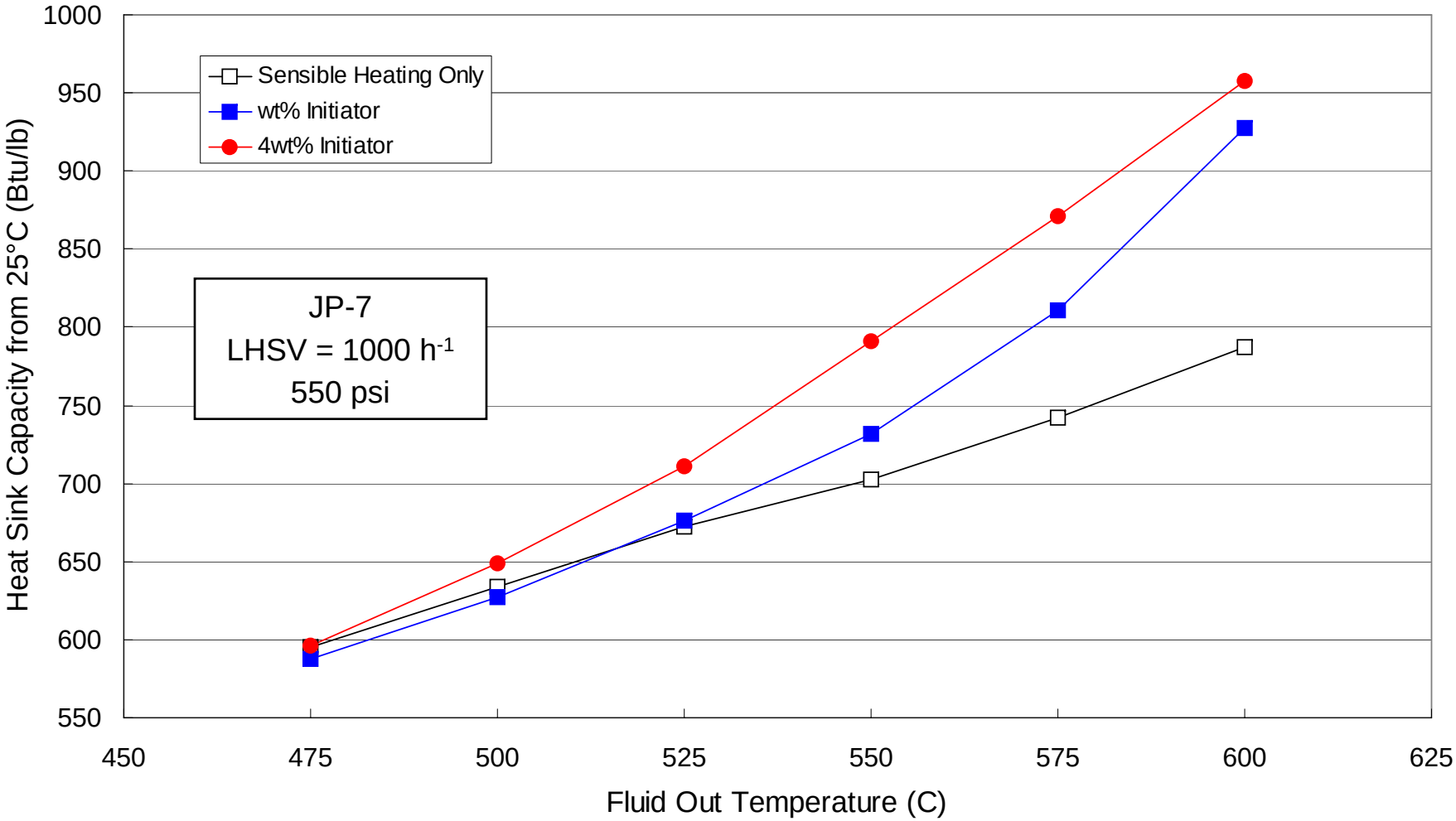
The Initiator Improves the Heat Sink Capacity of JP-7



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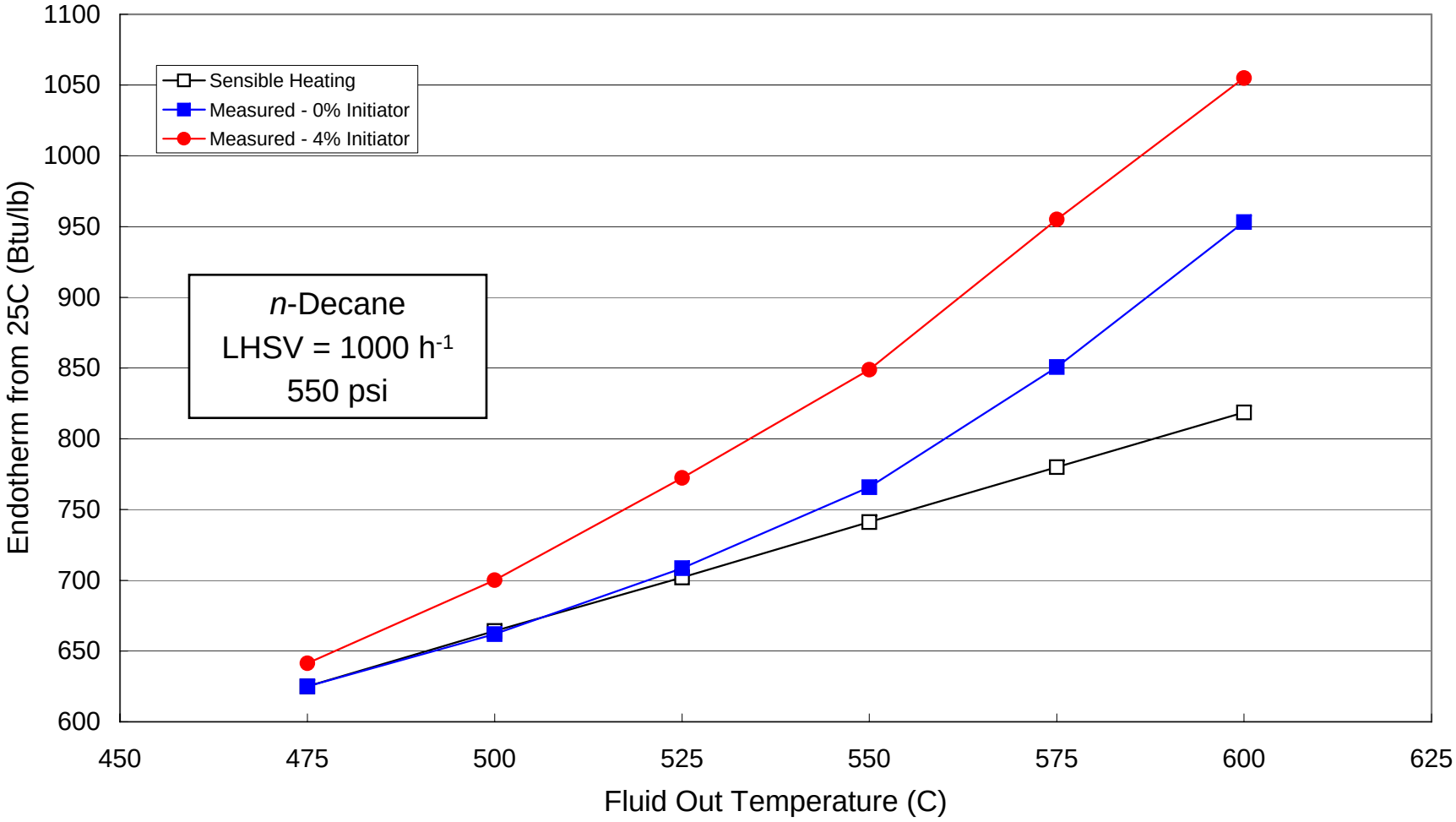
Substantial Increases in *n*-Decane Heat Sink Capacity



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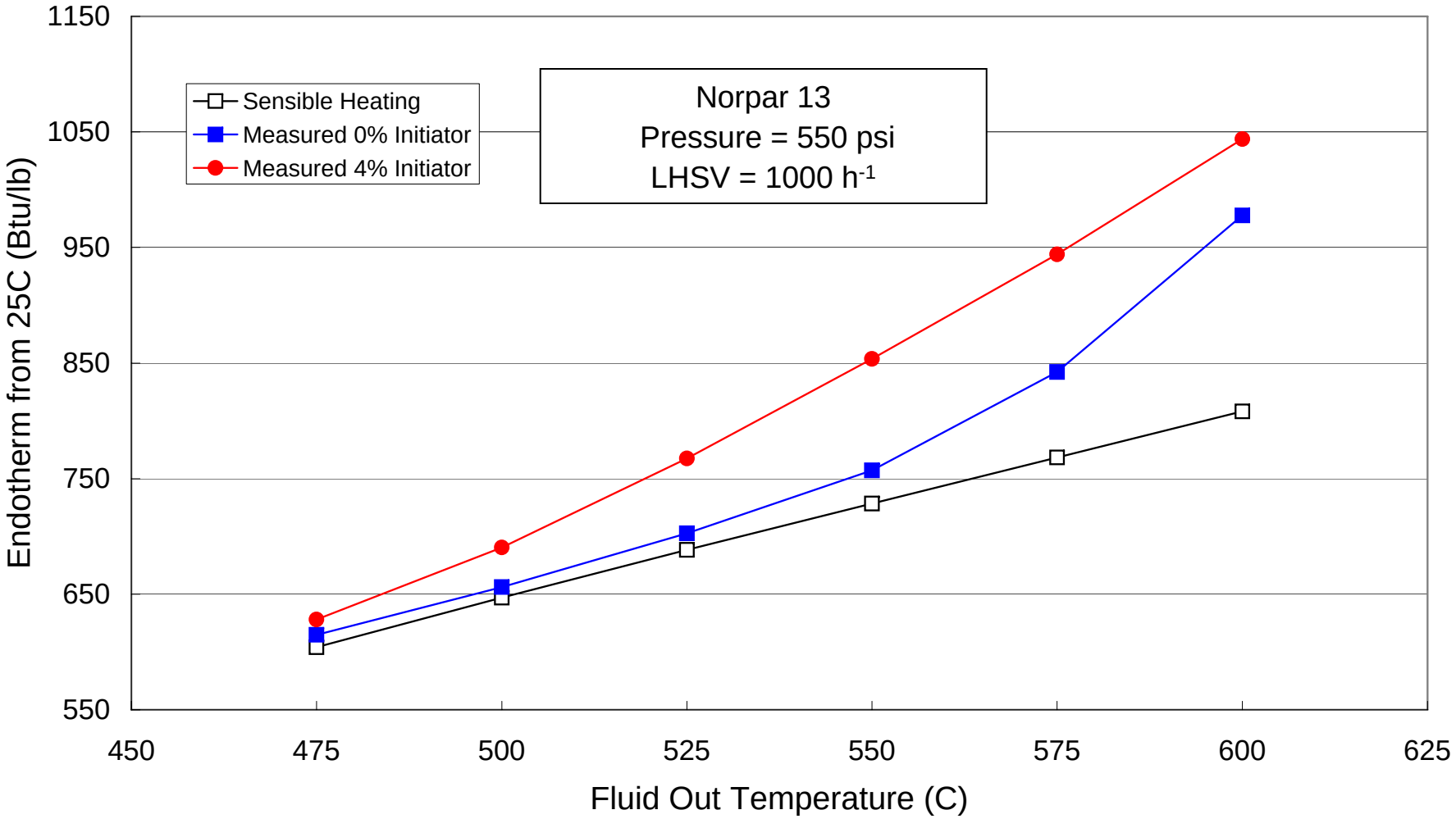
The Initiator is Very Effective with a Mixture of Normal Paraffins



endotherm_plots_2

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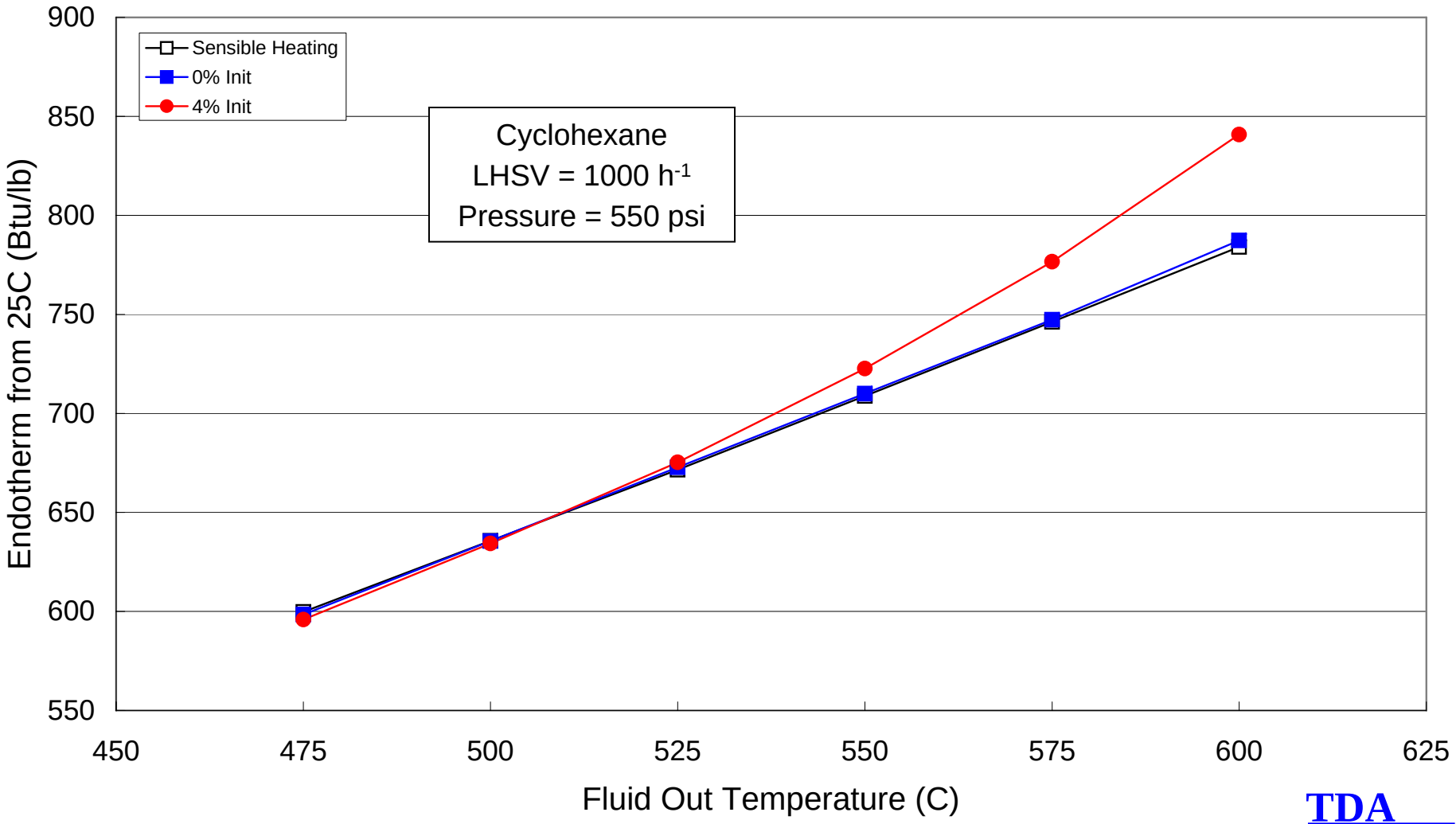
Cyclohexane is Thermally Stable without Initiator



endotherm_plots_2

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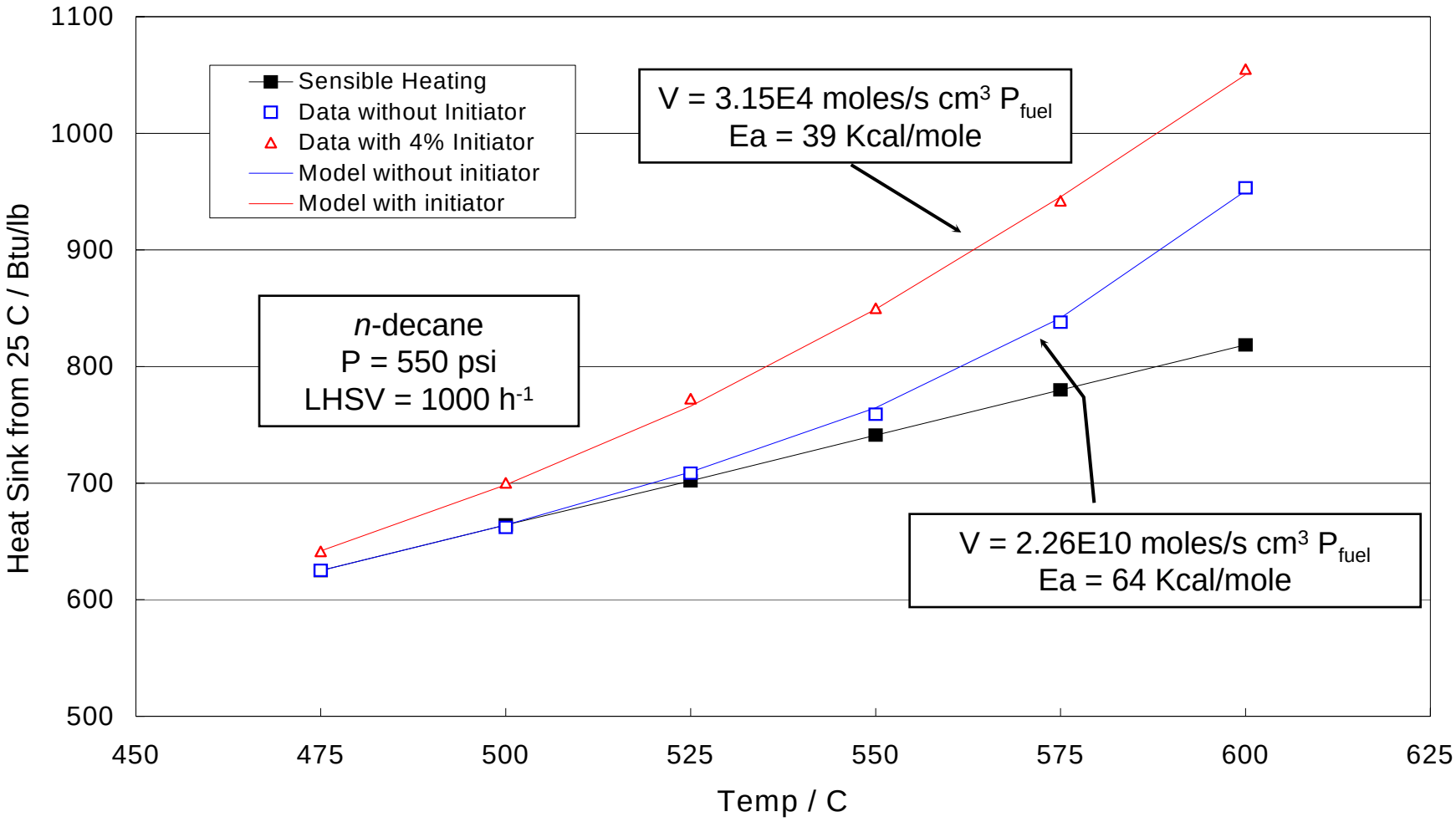
The Initiator Reduces the Activation Energy of the Cracking Reaction



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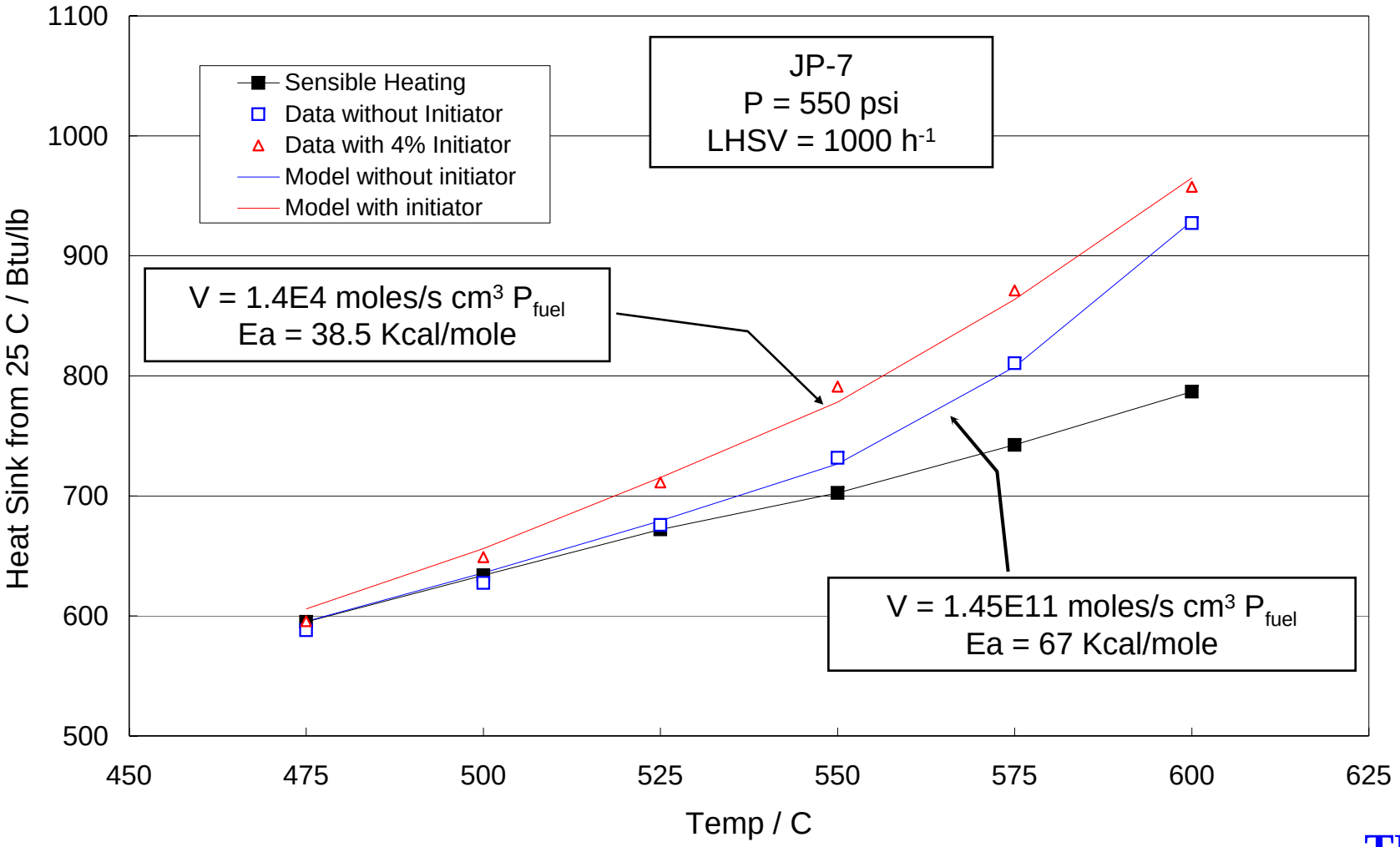
Kinetic Data for JP-7



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Design and Construct Pilot Scale Air/Fuel Heat Exchanger

- Demonstrate heat sink capacity under realistic conditions.
- Heat flux of approximately 100,000 Btu/ft^2 h.
- $T_{air\ in}$ = 780°C, $T_{air\ out}$ = 350°C
- $T_{fuel\ in}$ = 65°C, $T_{fuel\ out}$ = 450°C

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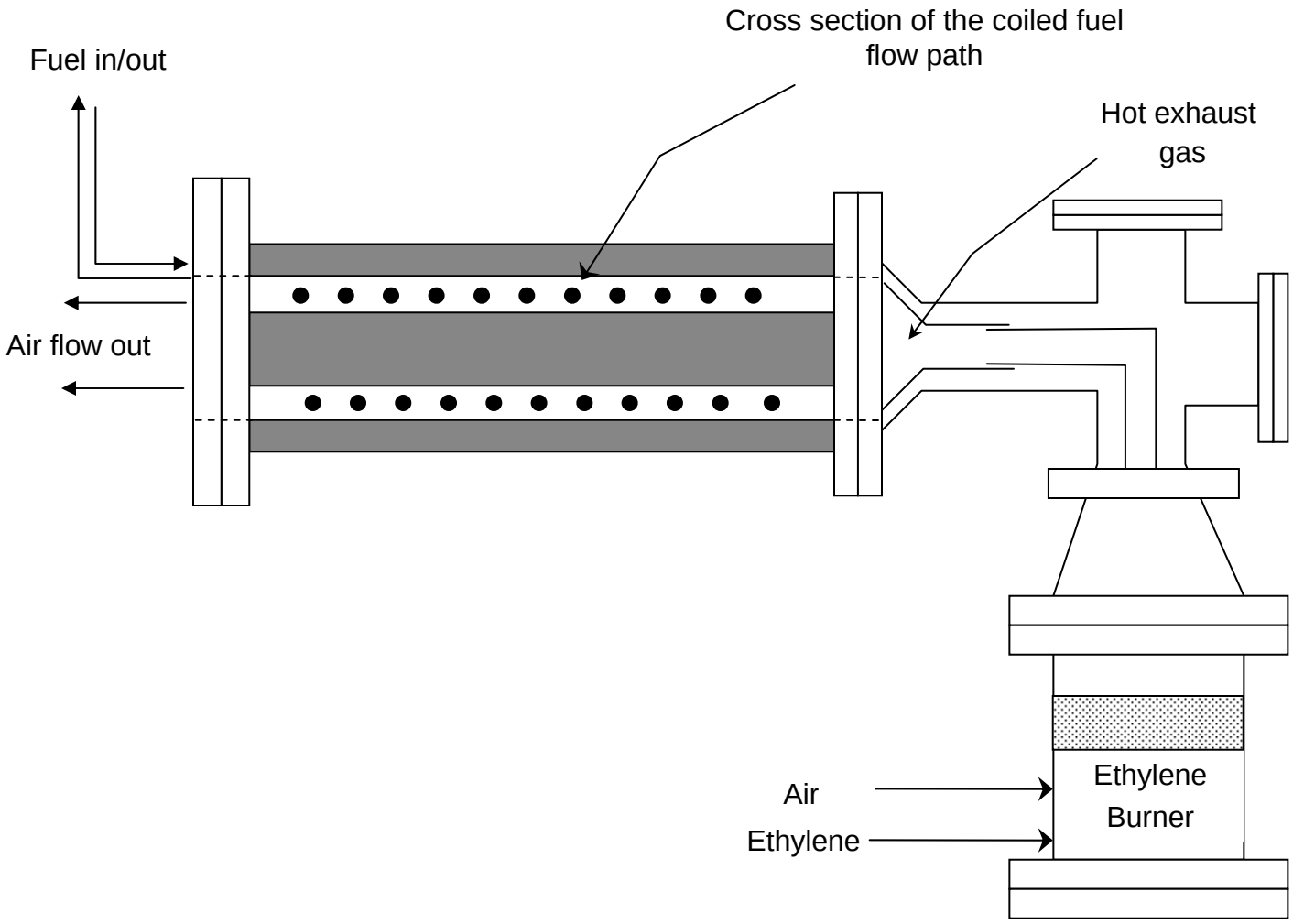
Schematic of Ethylene Burner and the Heat Exchanger



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Finned Inconel Tubing for Fuel

32 feet total finned tubing length
25.5 in overall unit length
3 in coil diameter
41 total wraps
~9.4 in length per wrap

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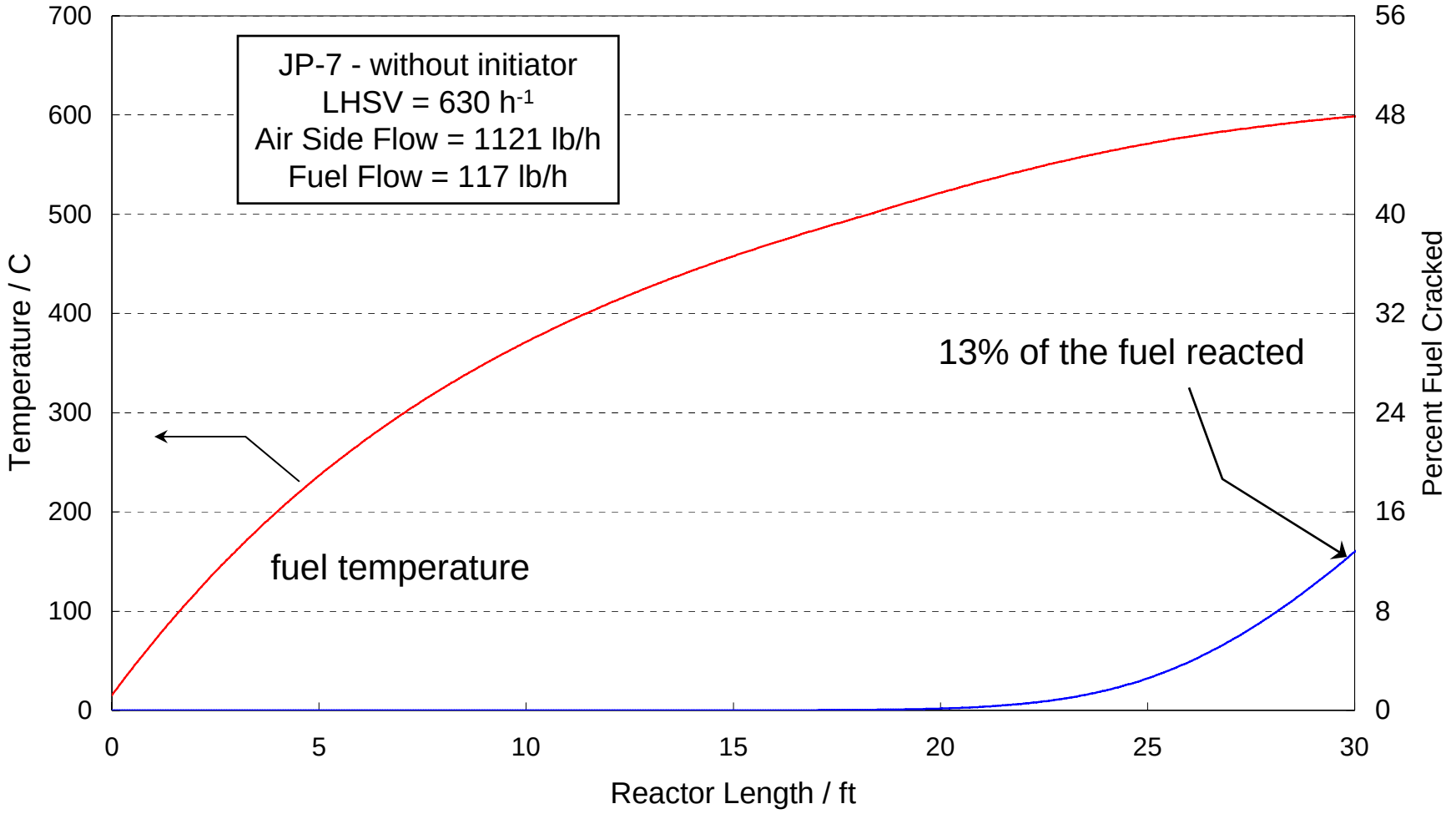
Kinetic Model Used to Predict Cracking Level



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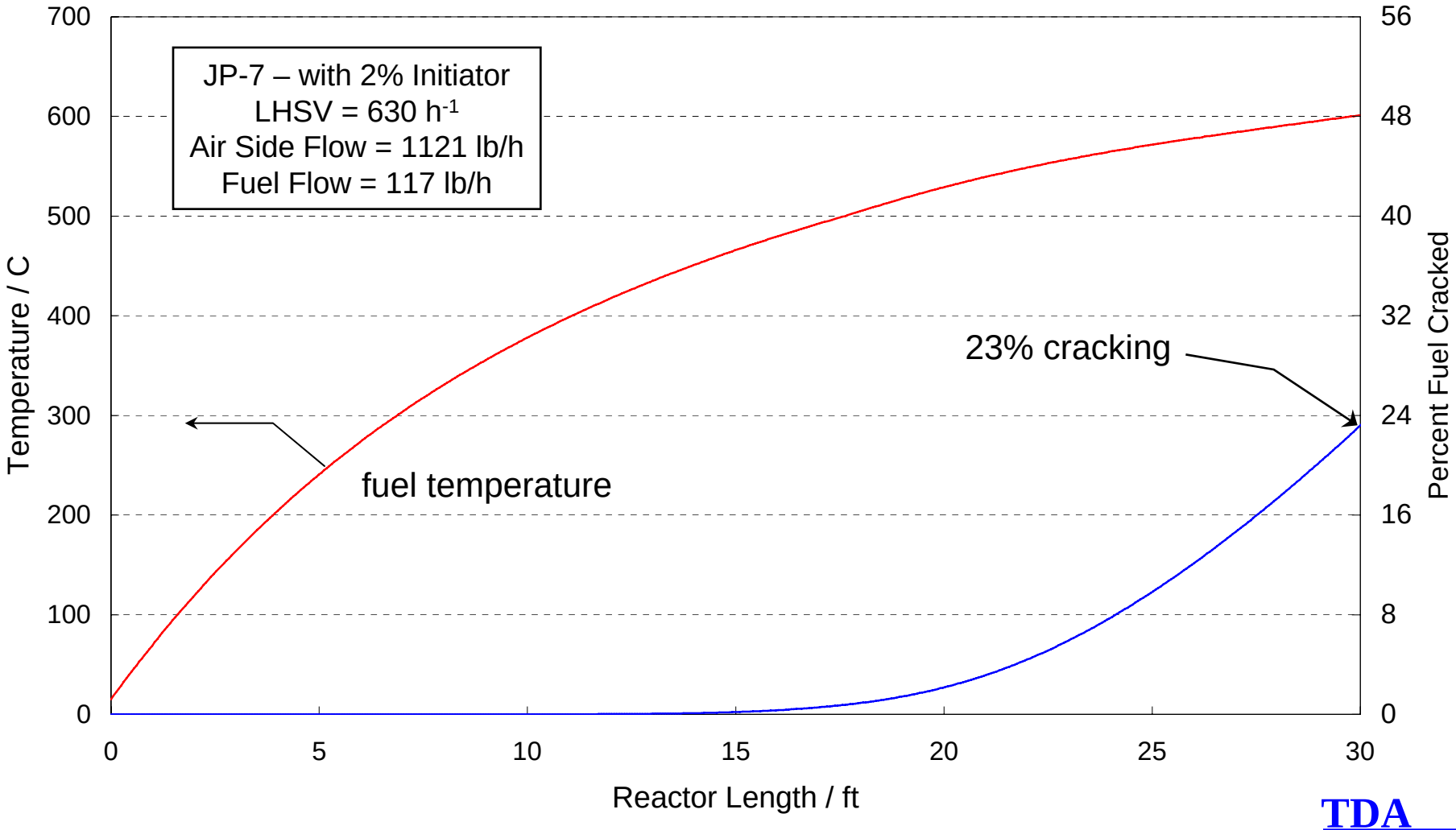
Addition of Initiator Increases the Fuel Cracking Reaction



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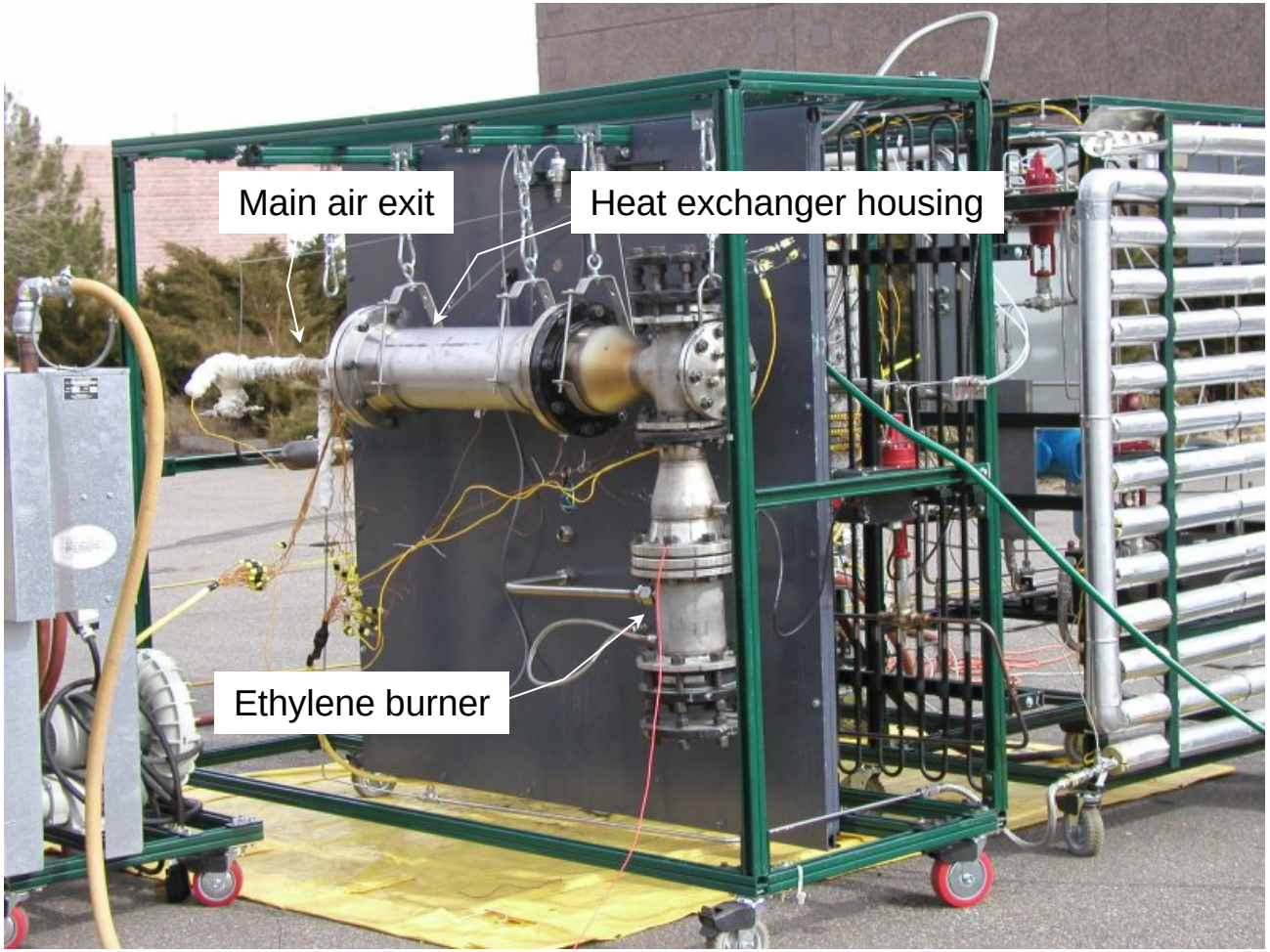
Installed in Test Rig



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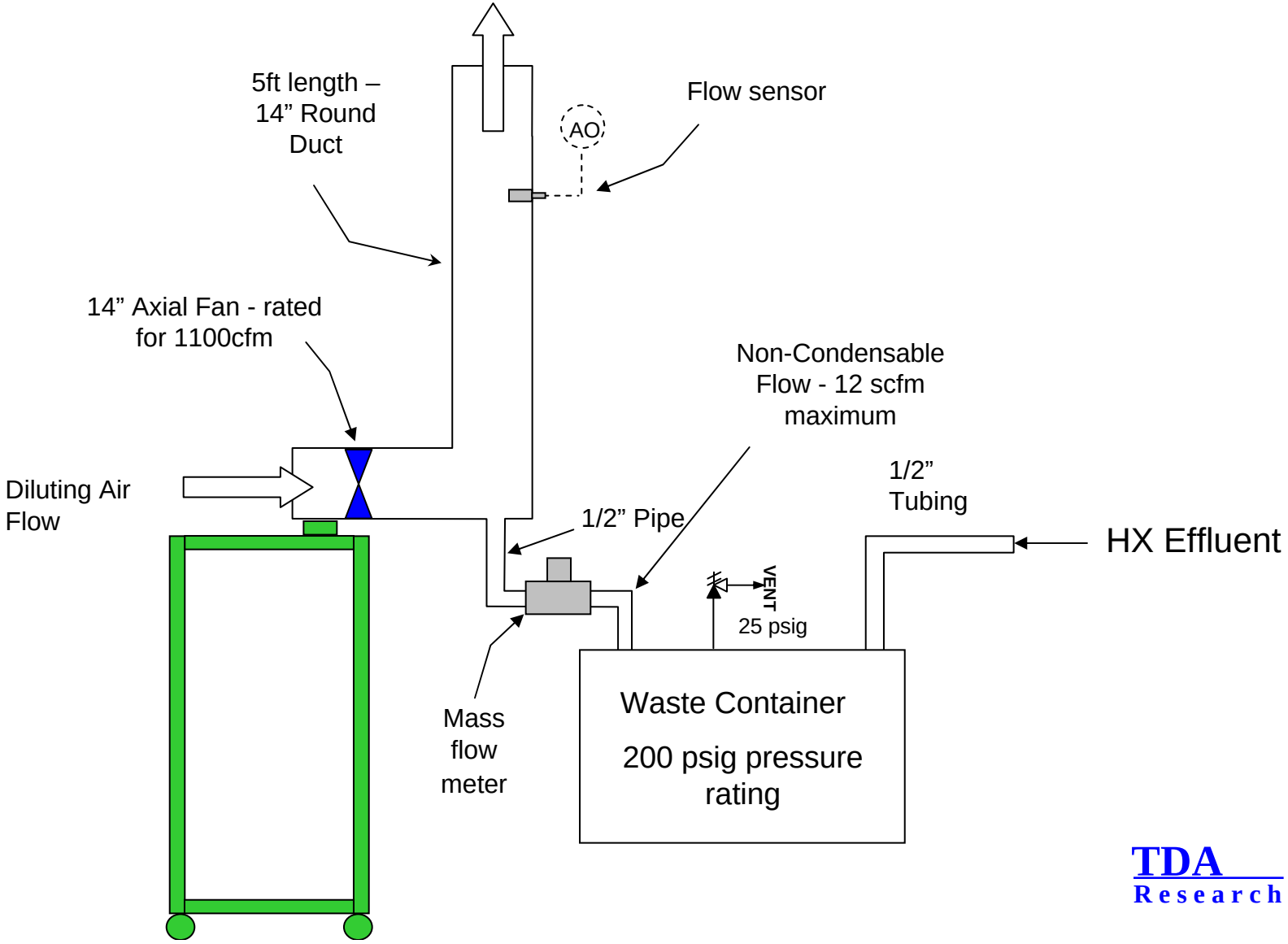
We Measured Non Condensable Flow



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Pilot Scale Rig in Operation

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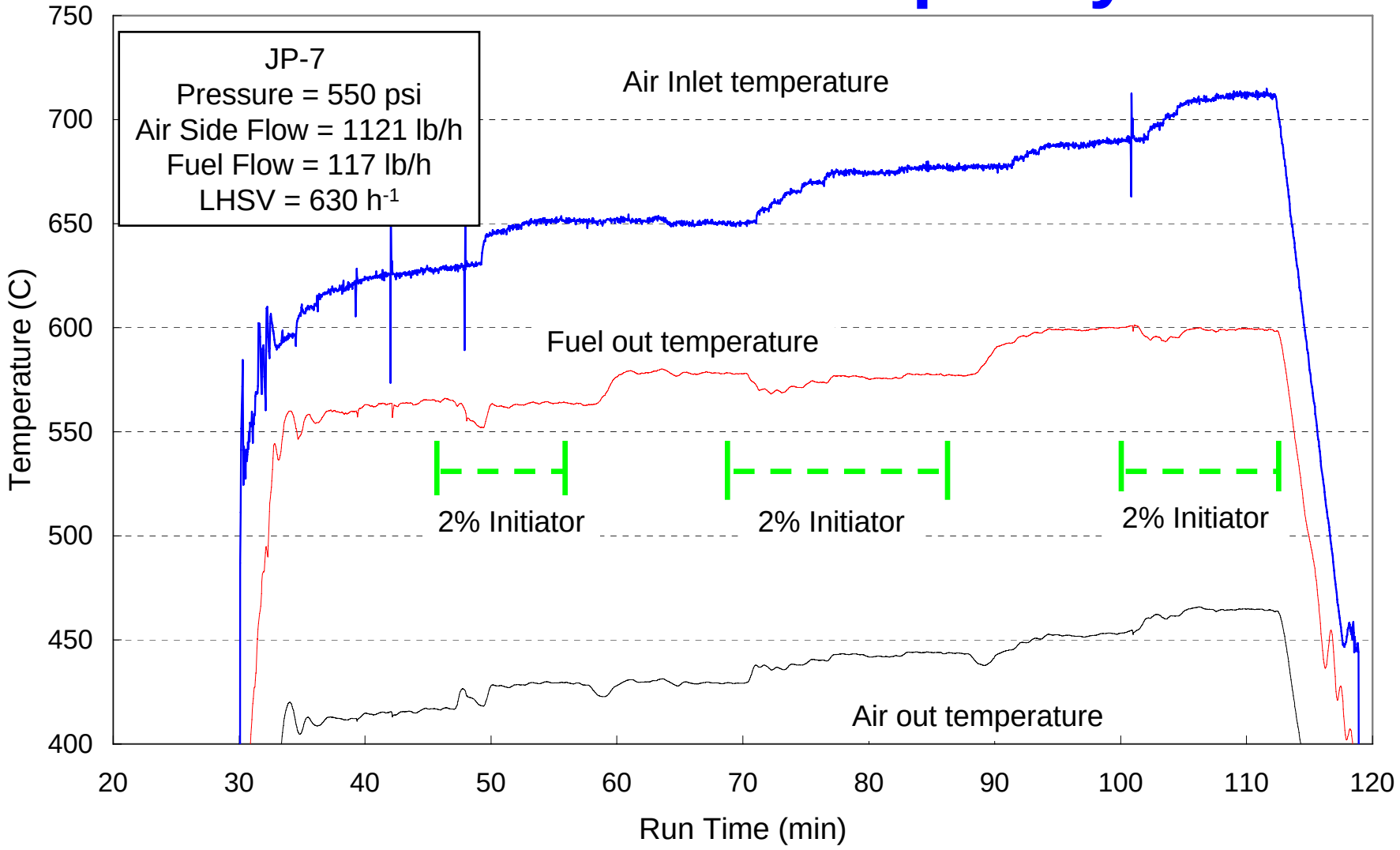
Initiator Causes an Increase in the Fuel Heat Sink Capacity



2_26_JP7_Data

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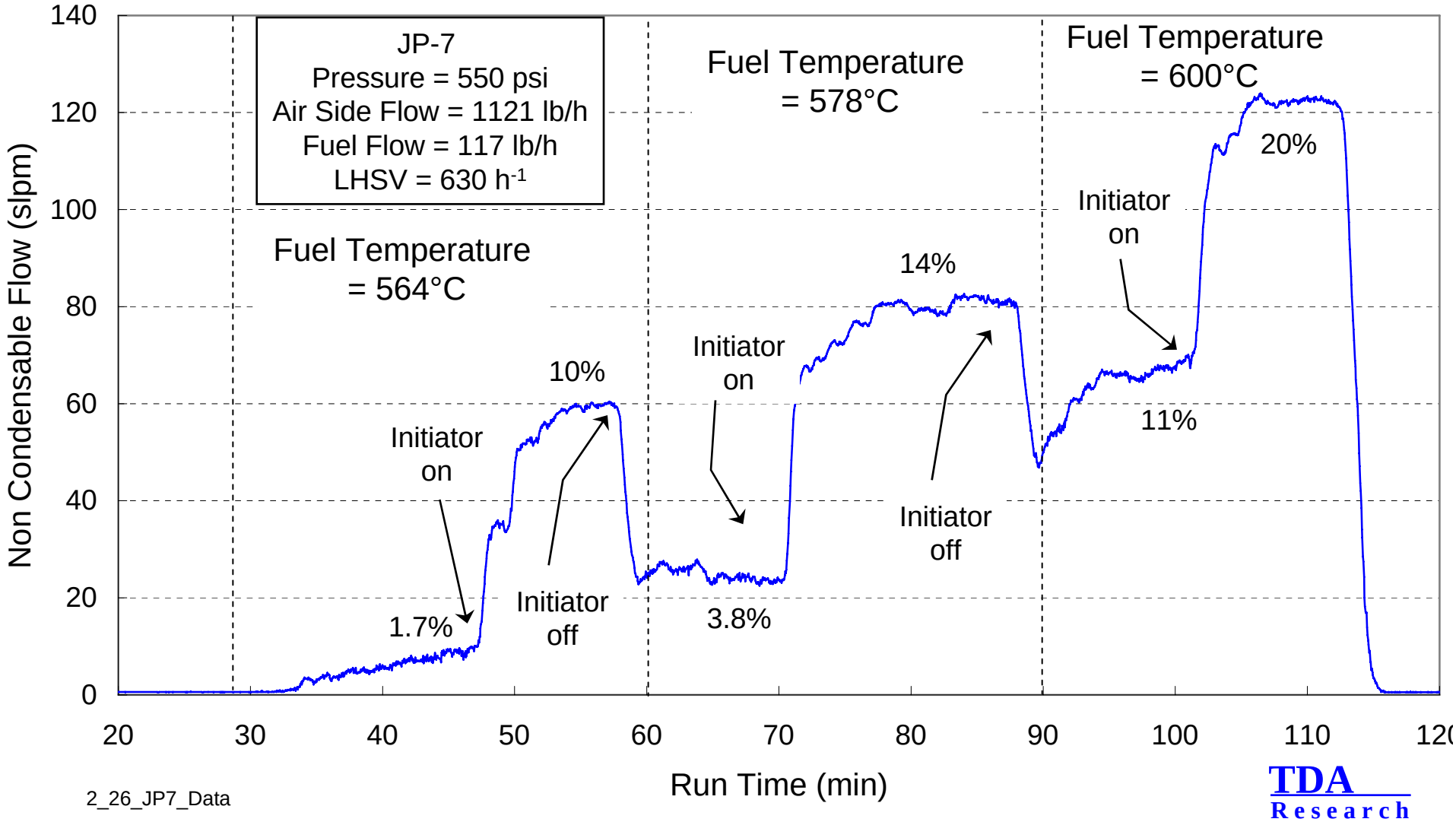
Initiator Produces Significant Increase In Non Condensable Flow



2_26_JP7_Data

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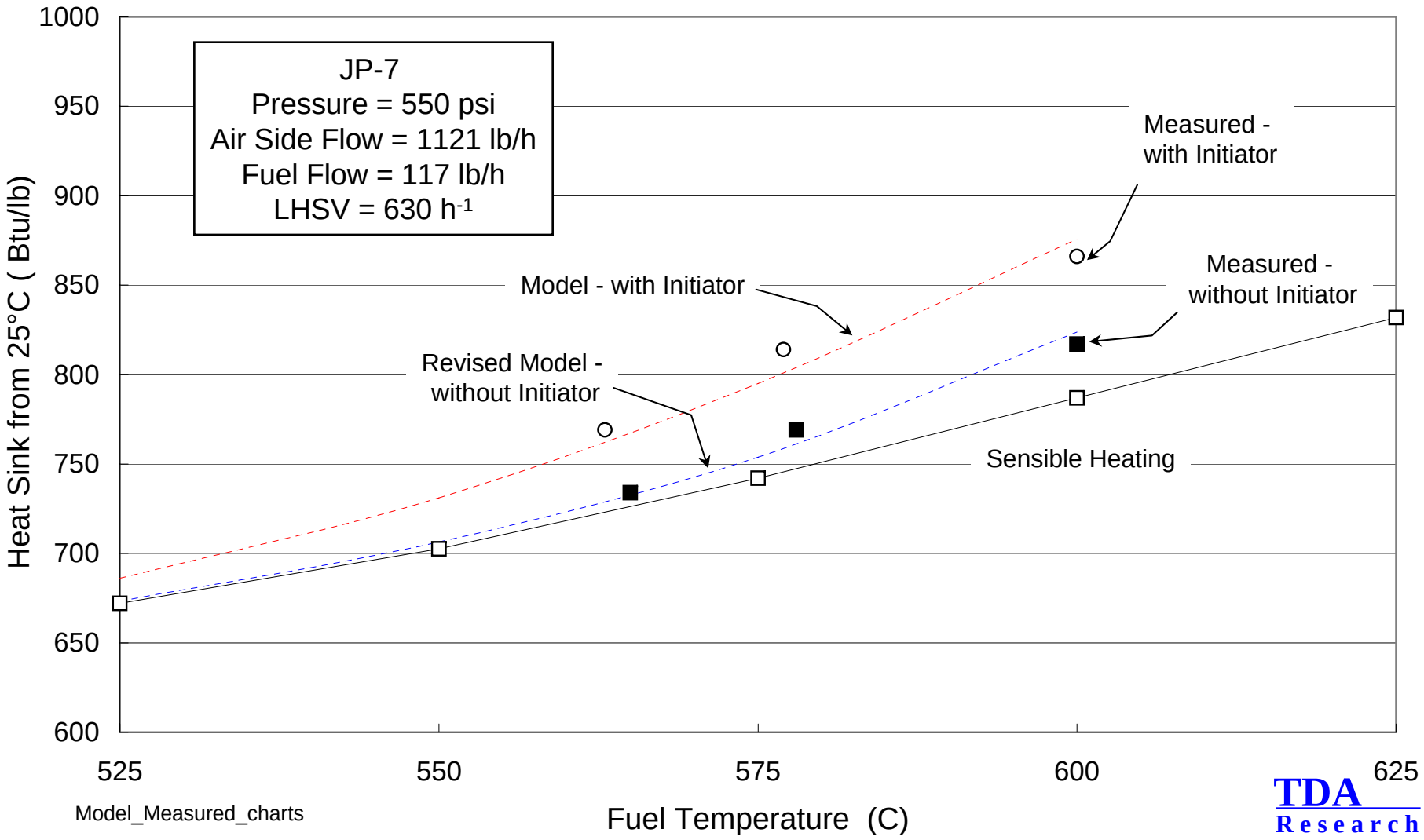
Model for JP-7 Fits the Data Well



Model_Measured_charts

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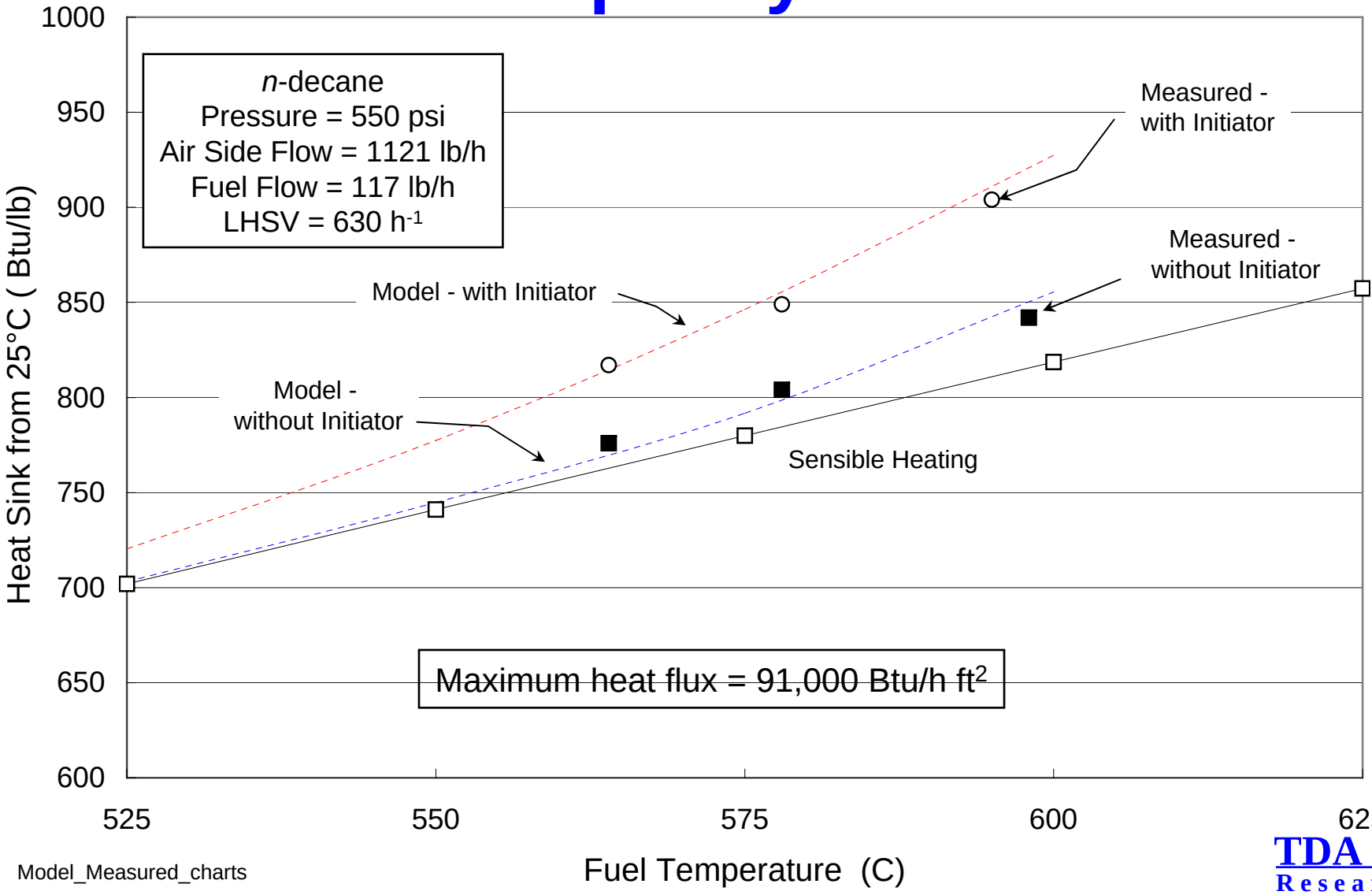
Initiated Cracking Adds Substantial Heat Sink Capacity for *n*-Decane



Model_Measured_charts

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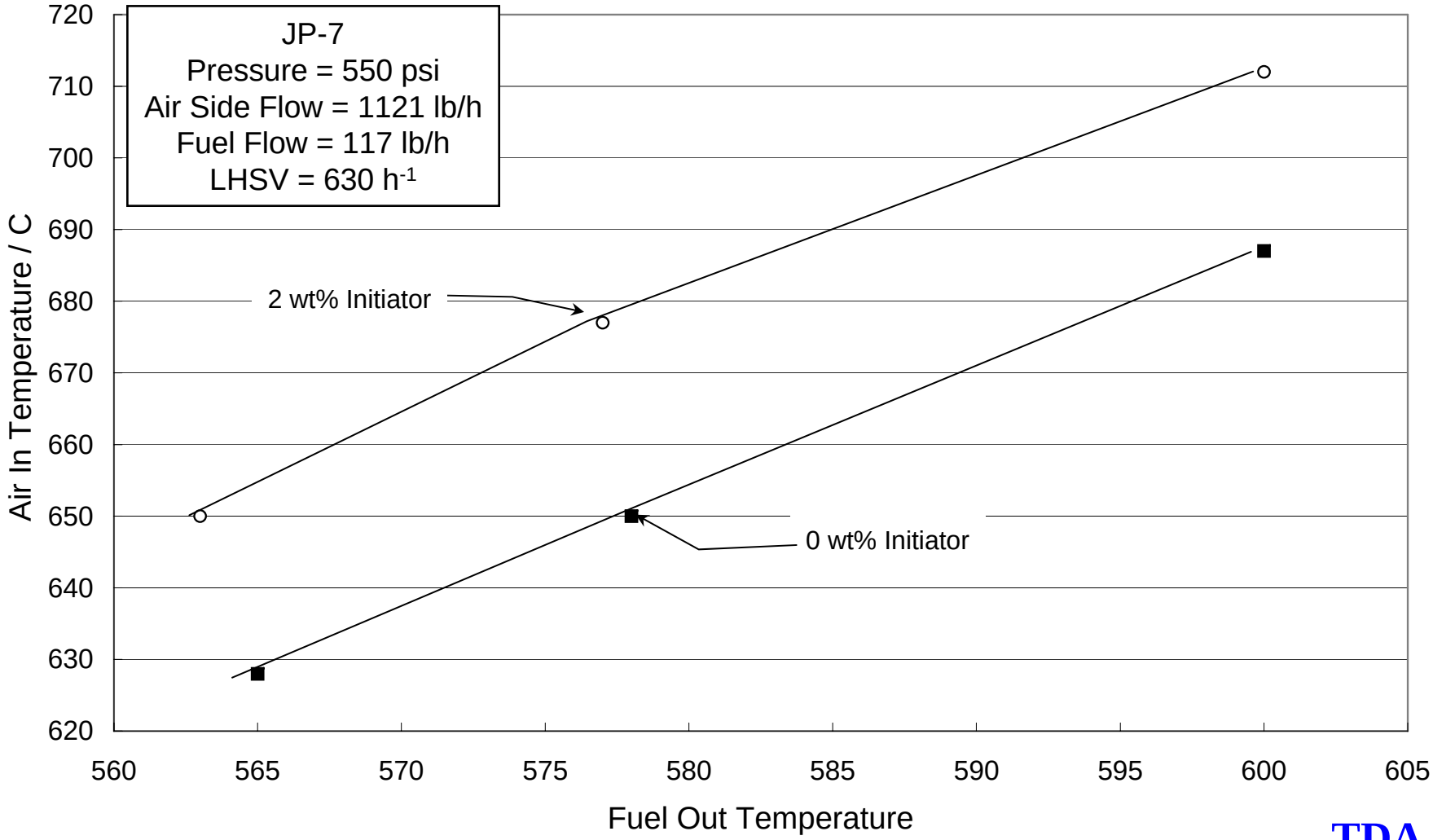
The Initiator Can Reduce the HX Temperature



Model_run_summaries

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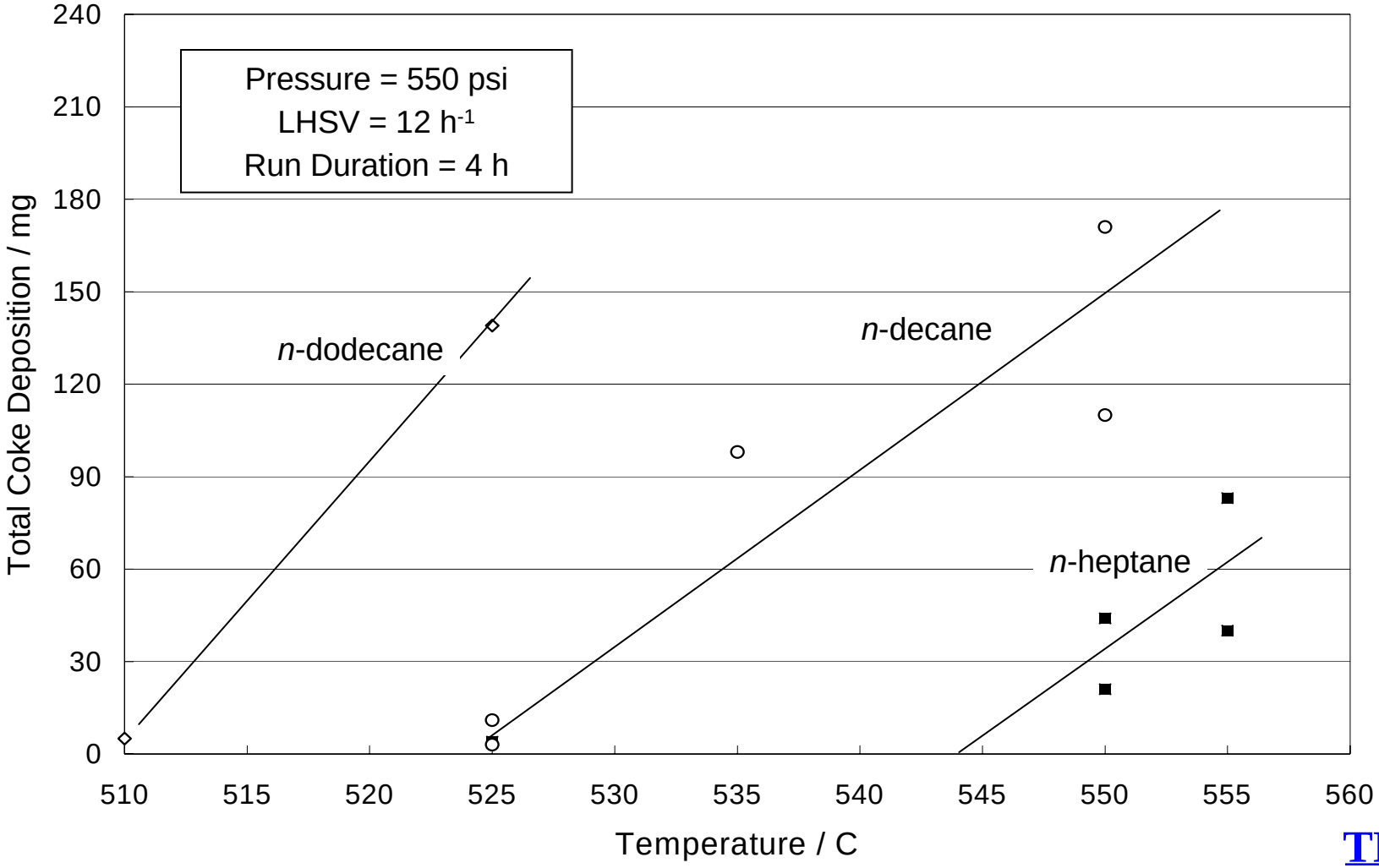
Coke Deposition Rates are a Strong Function of Temperature



From Coke_compare

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Summary

- The TDA initiator produces significant increases in the fuel heat sink capacities of JP-7 and model fuel compounds.
- The initiator reduces the activation energy for the thermal cracking reaction.
- We demonstraed the effectivness of the initiator in a fuel/air heat exchanger that operated at realistic heat flux.
- The initiator reduces the HX temperature, which could substantially reduce coke deposition.

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